of stress a given body of rock can support before fracturing also lack a direct connection between fluid transport and mechanical properties. The research outlined below explores these issues both qualitatively and quantitatively using a novel application of discrete numerical models of coupled fluid and solid physics.

In strongly coupled fluid-solid systems the evolution of the solid framework is influenced by the fluid and vice versa. These couplings often result in changes of the bulk material properties (i.e. permeability and failure strength) with respect to the fluids ability to move through the solid and the solids ability to transmit momentum. Feedbacks between fluid and solid framework ultimately play key roles in understanding the spatial and temporal evolution of the coupled fluid-solid system. Continuum numerical models of these systems attempt to capture these changes by using complicated constitutive relations, simple rules, or choosing to ignore them altogether. This often results in less than acceptable comparisons with observed behaviors. To address these issues discrete numerical models of the coupled systems based on fundamental fluid and solid physics have been developed. These models use direct simulation of fluids and solids to capture the evolving behavior of the system of interest. Our formulation couples the popular discrete element method (DEM) for solid mechanics and the lattice-Boltzmann method (LB) for solving the Navier-Stokes solutions of incompressible fluid flow.

To examine the role of fluids in strongly coupled systems we developed 2-dimensional models of fracture initiation and propagation using the coupled DEM-LB model. Models exploring the rates of propagation and the initiation of fractures were developed to help isolate the role of mechanical and hydrologic heterogeneities on the overall system behavior. Preliminary results indicate that the model captures linear poro-elastic behavior. Comparisons of model results to simple laboratory experiments indicate that the general elastic and in-elastic behavior of the model is quite realistic. Finally, more complicated models of fracture initiation and propagation in saturated media point towards a hydrologic control on fracture development and behavior.

URL: http://www.nmt.edu/~dboutt/AGUFall02/

H71B-0820 0830h POSTER

Fully Determined Fluid Velocity Fields for Complex 2D Media With Multi-Scaled Heterogeneity.

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Numerical schemes for fluid flow in complex rock geometries rely on comparison with existing empirical data for their validation. Such data, when available, are generally limited to non-unique, bulk measurements of properties such as hydraulic conductivity and permeability and are not adequate to fully validate complex numeric schemes.

Here we describe an experimental system which has been developed to fully quantify velocity fields throughout synthetic two-dimensional heterogeneous media. We first create a digital image with the desired combination of matrix and fracture porosity, incorporating detail over several orders of magnitude. This image is then translated into a physical medium using either stereolithography or wire EDM machining. The result is a flow cell comprising two transparent plates with a thin section of material, identical to the digital image of the medium, between them. In order to observe and measure fluid velocity, the flow cell is integrated in a purpose built experimental rig and a controlled flow of fluid, seeded with neutrally dense microparticles, is induced. By illuminating the flow seed and acquiring temporally separated images of sub-areas of the medium, the local velocities can be determined at high-resolution using a particle image velocimetry technique.

The apparatus is currently being used to investigate a range of problems including the importance of nonlinear interactions between matrix and fracture flow, scaling laws in the region of the percolation threshold and the scaling of the velocity flow field relative to the scaling of the material geometry, the latter with a view to identifying potential rules for upscaling of fluid simulations. Simultaneously, the same investigations are conducted using a modified Lattice Boltzmann scheme in order to assess the extent to which the numerical scheme accurately predicts flow.

H71B-0821 0830h POSTER

Measuring Changes in Fracture Aperture During Injection to Estimate Characteristics of Fractured Rock Near a Well

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Fracture networks are critical to ground water flow, but details of the geometry of networks in the subsurface can be difficult to determine with currently available technology. Sheet fractures, or other flat-lying fractures, are an important component of fracture networks in crystalline rock. Using a televiewer, or other borehole geophysical technique, it is possible to determine the depth a sheet fracture intersects a borehole, but it is more difficult to determine the size of the fracture and its connectivity to other fractures in the network. The aperture of a sheet fracture will change in response to pressure changes during a hydraulic well test, and the amount that the aperture changes will depend on both the size of the crack and how it is connected to the network. We are developing a field test that measures changes in aperture during a well test to estimate fracture geometry. The test uses a borehole extensometer between straddle packers to measure changes in aperture, and transducers to measure pressure during and after a hydraulic well test conducted by injecting at a constant flow rate. In general, the fracture opens as pressure increases during injection, and closes as pressure decreases during recovery. A coupled model of deformation and fluid flow is inverted to estimate fracture parameters that best predict the records of aperture and pressure.

Efforts toward developing this test have focused on designing and fabricating instrumentation for acquiring the field measurements, and deriving theoretical analyses for interpreting the results. The borehole extensometer consists of two retractable anchors separated by connecting rods attached to a submersible LVDT. The anchors are designed to lock themselves in place once actuated, thus minimizing creep over time. Another application for this device is to measure long-term changes in fracture aperture due to Earth tide or other effects, so it is important to reduce creep effects. The anchors are deployed on opposite sides of a fracture and they are displaced as the fracture dilates. Lab tests show that the lower limit of resolution is approximately 0.1 micron, and temperature changes both downhole and above ground appear to be a major threat to resolution. The connecting rods are configured to minimize overall length changes of the device owing to downhole temperature changes. Above ground, the data acquisition system is held at a near constant temperature in an insulated container to reduce spurious displacement measurements caused by changing the temperature of the electronics. The system has recently been deployed in the field at shallow depths, and we expect to obtain data after completing the packers and winch system that will be required to deploy the device at working depths (30 to 100 m). Simple analytical models, and a more complete semi-analytical model are being developed to interpret the results of the field tests. The semi-analytical model determines the pressures and aperture changes during injection of water into a flat-lying fracture intersecting a borehole. The solution is obtained by iterating between one analysis for fluid-flow and another for elastic displacements of the fracture using methods developed for modeling hydraulic fracture propagation.

URL: http://www.ces.clemson.edu/~tschwei/prebex/overview.htm

H71B-0822 0830h POSTER

Permeability of 2D Multiscale Fracture Networks

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Modeling fluid transfers in fractured rocks remains one of the main challenge of modern hydrology. Fractures are key structures for the migration of fluids, but their spatial heterogeneity and complexity at all scales make difficult the definition of simplified, but relevant, flow models. A major difficulty comes from the multiple scales involved. Fractures occur at all scales, from micro-cracks up to pluri-kilometric faults. Beyond such a characteristic that implies a large distribution of fracture size, the geometry of fracture networks is also characterized by a wide distribution of orientations, of apertures and by a spatial repartition of fracture densities which may be inhomogeneous.

This complex geometry raises some fundamental issues about the hydraulic characterization and modeling of fractured media. The definition of a representative elementary volume which is basic to classical homogeneous models is in particular questionable in multiscale fracture networks that do not present any apparent characteristic scale. Even the definition of a pertinent scale, or scale range, to describe the geometry of a fracture networks, or to measure the hydraulic properties of the system, is not explicit.

In this paper, we give some insights into the way to deal with two-dimensional multi-scale fracture networks. We especially focus on the consequences of some basic statistical properties of fracture networks : (i) the fracture length distribution, (ii) the spatial correlations between fractures, and (iii) the fracture aperture distribution. Fracture length defines the spatial extent of the heterogeneity that a fracture may potentially induce on flow while fracture aperture defines the intensity of this flow heterogeneity by fixing fracture permeability. On the other hand, spatial correlations may enhance or limit the efficiency of the fracture network to carry flow at the global scale.

We assume in the model that both the spatial distribution and the fracture length distribution are following power laws. Beyond the relevance of this model to natural fracture networks, that we tested on some natural examples, the power-law distribution model has the interesting property to have no characteristic length scale except its endmost limits. Using Monte-Carlo simulations, we first analyzed the consequences of these geometrical features on the connectivity property of stochastic fracture networks. We show that depending on the relative value of the fractal dimension, D, and of the power-law length exponent, a, the connectivity may be controlled either by the smallest or largest fractures. The variations of the connectivity with scale depends also strongly on the relative value of a and D. In term of permeability, we analyzed in particular the definition of a relevant scale, or scale range, for fluid flow, and of the pertinent flow model. We obtain a rich phenomenology when covering the range of all possible fracture distributions. For instance, a large length distribution combined to a large aperture distribution may lead to a great increase of the permeability with scale. On the opposite, the spatial correlation between fractures tends to lead to a decrease of the permeability with scale. Through the analysis of the network equivalent permeability as a function of the fracture network structure, this work allows a better understanding of the relationships between geometrical and hydraulic properties of fracture networks.

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H71C MCC: Hall C Sunday 0830h

Interannual Variability of the Hydrologic Cycle I Posters *(joint with NG, A, B, GC)*

Presiding: **P Kumar,** University of Illinois, Urbana-Champaign**; U Lall,** Columbia University

H71C-0823 0830h POSTER

Long-memory Models for Hydrologic Prediction in the la Plata Basin.

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Long-term fluctuations in both rainfall and runoff in the la Plata drainage basin (area 3.1 million square kilometers) have been widely reported. In the case of the Parana River at Corrientes, meteorologists have detected a "near-decadal" fluctuation from which predictions of runoff have been published with lead-time of ten years. If runoff is predictable to this extent, then it should be possible to predict it by means of statistical models with long memory, of the type ARIMA(p,d,q) with fractional d in the range from zero to 0.5. This paper presents results obtained when models of this type were fitted to the flow records from the Parana at Corrientes and other long-term flow and rainfall records from the South American sub-continent. Methods of model fitting are compared, and predictions are presented together with their confidence intervals.

H71C-0824 0830h POSTER

Understanding Controls on Historical River Discharge in the World's Largest Drainage Basins

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Long-term (20 year) river discharge records from 30 of the world's largest river basins have been used to characterize surface hydrologic flows in relation to net precipitation inputs, ocean climate teleconnections, and human land/water use patterns. Comparisons of paired station records at upstream and downstream discharge locations within each major river basin suggest that the relatively 'natural' discharge signals represented in upstream discharge records are sustained in the downstream station records for nearly two-thirds of the drainage basins selected. River basins that showed the strongest localized climate control over historical discharge records, in terms of correlations with net basin-wide precipitation rates, are located mainly in the seasonally warm temperate and tropical latitude zones, as opposed to river basins located mainly the higher latitude zones (above 45 degrees N). Ocean climate indices such as the NINO1+2 and NINO3+4 correlate highly with historical interannual patterns in monthly river discharge for only four of the selected discharge station records, namely on the Amazon, Congo (Zaire), Columbia, and Colorado (Arizona) rivers. Historical patterns of cropland development and irrigated areas may explain the weak climate correlations with interannual patterns in monthly river discharge rates for at least one-third of the major river drainages selected from the historical discharge data set.

URL: http://www.ahpcrc.umn.edu/nasa-umn/

H71C-0825 0830h POSTER

Hydrological and climatological impacts of the North Atlantic Oscillation in Norway and Sweden

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The North Atlantic Oscillation (NAO) has a discernable impact on the availability of water in reservoirs used for hydropower production in Norway. The NAO signal in precipitation is much weaker in Sweden, because the Kjolen mountains in Norway block the passage of much of the precipitatible water into Sweden. However, temperature in both countries is highly correlated with the NAO index. Hydrological and climatological impacts of the North Atlantic Oscillation (NAO) in Norway and Sweden are discussed, as well as the impact of the NAO on the supply and demand of hydropower.

H71C-0826 0830h POSTER

Use of extended daily hydroclimatalogical records to assess hydrologic variability in the Pacific Northwest

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The National Climatic Data Center (NCDC) has recently created digital archives of daily climatological data (primarily precipitation and daily temperature maxima and minima) for the continental U.S. going back to the beginning of the instrumental records. Previous electronic archives were typically available only back to about 1948, with a few stations digitized back to the 1930's. As a result, most long-term hydroclimatalogical simulations have been limited to the second half of the 20th century. Reasonably good station coverage for the Pacific Northwest is now available back to at least 1915, which represents a 35-year extension of the available driving data for hydrologic model simulations. These long records, and the hydrologic simulations (e.g., of soil moisture, snow water storage, and runoff) derived from them make possible a better understanding of hydrologic variability in the 20th century. Of particular interest in the Pacific Northwest are hydrologic simulations of the severe droughts in the 1930s and 1940s. Using the newly available data merged with the previous archive, we have created a 1/8 degree data set of precipitation, temperature, and derived radiative forcings and other surface variables needed to drive the Variable Infiltration Capacity (VIC) macroscale hydrology model over a Pacific Northwest domain consisting of the Columbia River basin and coastal Washington and Oregon.. Records of naturalized streamflow for the Columbia River at The Dalles, OR are available for this same period, and these observed data are compared to simulated streamflow from the VIC simulations to evaluate the quality of the new data in comparison with the data previously available from 1948-1999. The raw data are also compared to a smaller number of higher quality HCN data records in an effort to identify temporal inhomogeneities or other biases in the data. From the new analysis, we assess implications of the longer derived records to our previous assessments of interannual and interseasonal variability in key hydrologic variables such as snowpack and soil moisture storage.

H71C-0827 0830h POSTER

Multiyear Estimates of Evaporation from a Watershed

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Estimates of the evaporative losses from the Walnut River Watershed in Kansas were made with the parameterized subgrid scale (PASS) model and applied in an evaluation of the hydrological balance for the five-year period 1996-2000. The PASS model uses routine, spatially sparse surface meteorological data and satellite remote sensing data to calculate surface evapotranspiration rates over extended areas. The PASS model is observationally driven, makes use of extensive parameterizations of surface properties and processes, and does not rely on mesoscale meteorological models. Heteorogeneities in surface conditions are spatially resolved to an extent determined primarily by the satellite data pixel size. For the period of the 1997 Cooperative Atmosphere-Surface Exchange Study field experiment at the Walnut River Watershed, estimates of vertical moisture fluxes from PASS agreed well with surface-based and aircraft-based eddy covariance measurements. Current work focuses on simulation of the water balance over the Watershed area of about 5000 square kilometers for a period of five years, in part to evaluate and study interannual variability. Surface vegetative conditions were described by analysis of biweekly, composite, 1-km-resolution NDVI (normalized difference vegetation index) data products. Radar-based estimates of precipitation estimates were obtained from the regional forecast center. Preliminary results indicate that estimates of accumulated soil moisture loss by evapotranspiration match fairly well with the soil moisture loss inferred roughly from precipitation and stream gauge measurements.

H71C-0828 0830h POSTER

Representing interannual variability in daily rainfall sequences

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Many traditional methods of daily rainfall generation assume that the daily rainfall depends exclusively on the rainfall that occurred in the past one, two, or three days, an assumption that results in an underrepresentation of variability at longer time-scales. For example, the variability of seasonal and annual totals produced by these approaches is known to be lower than the respective observed values. Such reduced variability effects the representation of sustained droughts and years having low rainfall, features that are of great interest in catchment planning and management. We present an approach for stochastic generation of rainfall that does not suffer from the problems noted above. Rainfall is modeled using a two-step approach. The first step consists of generating a series of rainfall occurrences that patterns the day-to-day, inter-seasonal, and inter-annual variability observed in the historical rainfall occurrence record. Once the rainfall occurrence is generated, the next step consists of generating the rainfall amount on each day designated as wet. Both rainfall occurrence and rainfall amounts are modeled assuming a combination of an order-one Markovian dependence, along with selected discrete aggregate conditioning variables representing seasonal, annual and inter-annual aggregate values. Nonparametric statistical methods are used to formulate both simulation models. The approach is applied to daily rainfall from Sydney and Melbourne, Australia, and the performance of the approach is demonstrated by presentation of model results at daily, seasonal, annual, and inter-annual timescales. The resulting generated sequences provide a better representation of the variability associated with droughts and sustained wet periods than was previously possible.

H71D MCC: Hall C Sunday 0830h

Drought Analysis and Prediction II Posters *(joint with A, GC)*

Presiding: **J Valdes,** University of Arizona**; J Salas,** Colorado State University

H71D-0829 0830h POSTER

The Geographical Distribution and Recurrence Characteristics of Drought - A Global Perspective

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Various indices based on observational data are used to assess the geographical distribution and relative frequency of occurrence of drought events around the globe for the period 1950-1998. Droughts of various intensity, duration, and spatial extent are considered. The results indicate that, despite variability among the different indices, there appears to be preferred regions around the globe for recurrent drought events. In addition, some of these regions map onto areas typically affected by ENSO (with seasonal precipitation anomalies of like "sign") suggesting some potential predictability. The integration of real time global drought monitoring with seasonal forecasting efforts at the IRI will be briefly described in the context of probability of drought persistence.

H71D-0830 0830h POSTER

Circulation patterns associated with droughts over southern Africa

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The paper highlights the circulation patterns associated with droughts that have demonstrated the vulnerability of the socioeconomic development of around 200 million people from 14 the Southern African Development Community (SADC) countries to the vagaries of the climate system. The recent, apparently perennial droughts juxtaposed with floods across southern Africa have to be seen against the background of advances made by the scientific community in the understanding of the global ocean-atmosphere system. The paper seeks to contribute to such advances science is making in order to make humankind benefit from the knowledge science has provided. The data used in the analyses include actual rainfall from the SADC countries and those from the United States NOAA (NCEP/NCAR Reanalysis) data banks.

The paper briefly looks at the regional climatology of the SADC countries, which shows that rains fall within the period October during one year to March of the following year. Most of the damaging droughts have tended to occur during January to March. Thus, the more detailed analysis of the circulation characteristics has a focus of composite of these months.